REPORT DOCUMENTATION P, AFRL-SR-BL-TR-98- 0119 oproved 0704-0188

1. AGENCY USE ONLY (Leave Blank)	2. REPORT DATE 24 Oct 96	3. REPORT TYPE AND DATES COVERED Final (01 Dec 92 – 31 May 96)

4. TITLE AND SUBTITLE Mathematical Problems in Combustion	5. FUNDING NUMBERS F49620-93-1-0066
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) University of Illinois – Urbana Champaign Urbana, IL 61801	8. PERFORMING ORGANIZATION REPORT NUMBER
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) AFOSR/NM 110 Duncan Avenue, Room B-115 Bolling Air Force Base, DC 20332-8080	10. SPONSORING/MONITORING AGENCY REPORT NUMBER
11. SUPPLEMENTARY NOTES	
12a. DISTRIBUTION AVAILABILITY STATEMENT Approved for Public Release	12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Acoustic instabilities in gas turbines. There are many ways, in reactive systems, in which a phase change can arise between pressure fluctuations and the induced fluctuations in heat release, to trigger acoustic instabilities via the well-known Raleigh criterion. We have described a mechanism that was not previously recognized and reported this in the engineering literature, with the suggestion that it is responsible for the instability known as 'groaning' observed in gas turbines at low speeds. The abstract of this paper is:

Slip affects the response time of fuel sprays to acoustic fluctuations in a gaseous flowfield. This article describes how gaseous fuel is released by evaporation as an oscillating response to the acoustic velocity fluctuations, and so contributes to acoustic instability. This article discusses the differences due to the evaporation characteristics of various fuels (JP-4, JP-5, and D-2) as well as the effect of droplet size, inlet air temperature, air speed, and Reynolds number on mass response. For example, it is shown that instability will be driven harder at lower frequencies, higher gas velocities, and increased liquid volatility.

14. SUBJECT TERMS acoustic instabilities, turbines, "groaning"	15. NUMBER OF PAGES
	16. PRICE CODE

19980129 052

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

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Final Report: F49620-93-1-0066

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Objectives

This research is primarily concerned with theoretical studies of combustion problems that are relevant to the Air Force mission. This includes the following topics: detonations and their role in explosives; acoustic instabilities in premixed combustion, particularly in multi-phase media; the fundamental behavior of diffusion flames. In addition, tools developed in theoretical combustion are of value in the study of thermoset composites, an area of Air Force interest, and work has been carried out in this area.

Personnel

graduate students: D.Labij, C.Lewis
post-doctoral students: D.Lozinski (primarily funded from non-afosr sources), J.Yao (commenced May 1996)

Publications

[1] J.Buckmaster, "The role of mathematical modeling in combustion",

article in Combustion in High Speed Flows, J.Buckmaster, T.L.Jackson, A.Kumar, eds.,Kluwer Academic Publishers, 1994, pp. 447-459.

[2] J.Buckmaster, T.L.Jackson, A.Kumar, eds., Combustion in High Speed Flows, Kluwer Academic Publishers, 1994.

[3] M.DiCicco, J.Buckmaster, "Acoustic instabilities driven by slip between a condensed phase and the gas phase in combustion systems", American Institute of Aeronautics and Astronautics reprint, AIAA 94-0103, 1994.

[4] C.J.Lee, J.Buckmaster, M.DiCicco, "Intrinsic and acoustic instabilities in flames fueled by multiphase mixtures", Combustion Science and Technology, vol.98, 161-184, 1994.

[5] D.Lozinski, J.Buckmaster, P.Ronney, "Absolute flammability limits and flame-balls", Combustion and Flame, vol.97, 301-316, 1994.

[6] J.Buckmaster & T.Jackson The effects of radiation on the thermal-diffusive stability boundaries of premixed flames. . Combustion Science and Technology, 1994, vol. 103, pp.299-313.

[7] J.Buckmaster & A.Agarwal Unsteady spherical flames in dusty gases. . Combustion Science and Technology, 1994, vol.103, pp.191-206.

[8] J.Buckmaster & T.Takeno, eds. Modeling in combustion science. Lecture Notes in Physics, No. 449, Springer-Verlag, 1995, 369 pages.

[9] I.Fischer, J.Buckmaster, D.Lozinski, and M.Matalon Vapor diffusion flames, their stability, and annular pool fires. . Article in Modeling in Combustion Science, pp.249-257, 1995.

[10] J.Buckmaster & D.Lozinski. Some topics in reverse smoulder. Article in Modeling in Combustion Science, pp.308-314, 1995.

[11] D.Lozinski & J.Buckmaster Quenching of reverse smoulder. . Combustion and Flame, 102: 87-100 (1995)

[12] J.Buckmaster & D.Lozinski An elementary discussion of forward smoldering. , Combustion and Flame, 104: 300-310 (1995).

[13] M.DiCicco & J.Buckmaster The role of slip in the generation of acoustic instabilities in gas turbines. , Journal of Propulsion and Power, 12: 34-40 (1996).

[14] D.Lozinski & J.Buckmaster The fast-time instability of a simple deflagration. , to appear in Combustion and Flame (1996).

[15] J.Buckmaster Edge-flames and their stability. , Combustion Science and Technology, 115: 41-68 (1996).

[16] J.Buckmaster and T.G.Vedarajan Self-Heating Effects in Thermoset Composites. , to appear in Journal of Composite Materials (1996).

[17] J.Buckmaster and R.Weber Edge-flame holding, , to appear in the Proceedings of the 26th International Conference on Combustion, (1996).

[18] J.Buckmaster, A theory of shallow smoulder waves. IMA Journal of Applied Mathematics, 56: 87-102 (1996).

[19] J.Buckmaster Edge-Flames, . To appear in the Journal of Engineering Mathematics, (1997).

Major accomplishments

1. Acoustic instabilities in gas turbines. There are many ways, in reactive systems, in which a phase change can arise between pressure fluctuations and the induced fluctuations in heat release, to trigger acoustic instabilities via the well-known Raleigh criterion. We have described a mechanism that was not previously recognized and reported this in the engineering literature [13], with the suggestion that it is responsible for the instability known as 'groaning' observed in gas turbines at low speeds. The abstract of this paper is:

Slip affects the response time of fuel sprays to acoustic fluctuations in a gaseous flowfield. This article describes how gaseous fuel is released by evaporation as an oscillating response to the acoustic velocity fluctuations, and so contributes to acoustic instability. This article discusses the differences due to the evaporation characteristics of various fuels (JP-4, JP-5, and D-2) as well as the effect of droplet size, inlet air temperature, air speed, and Reynolds number on mass response. For example, it is shown that instability will be driven harder at lower frequencies, higher gas velocities, and increased liquid volatility.

2. Thermoset composites are widely used in air-frames, rockets, and other structures used by the Air-Force. It has been suggested that an ideal construction strategy would be to lay up an entire wing (say) and then send a cure front through the resin-fibre matrix to create the finished product. Thermoset composites generate heat during the curing process, and this process is a sensitive function of temperature. These are key characteristics of combustion processes also. There is therefore the hope that mathematical strategies developed in combustion could be valuable in the study of thermoset composites. This hope is increased by the recent development of a continuous curing process for thick composites in which a cure front travels through the material, since these cure fronts resemble constant-density deflagrations. We have applied this strategy in [16] whose abstract is:

We describe a simple mathematical strategy, familiar from combustion studies, which can be used to predict whether or not temperature spiking occurs when the thermoset composite specimen is cured in an autoclave. For large specimens, thermal spiking cannot be avoided in an autoclave, so that Kim, Teng, Tucker, and White have proposed an alternative process in which lay-up occurs contemperaneously with curing and consolidation. This steady-state process and its one-dimensional stability have been analysed by Teng for simple kinetic schemes using an asymptotic approach, but we describe a non-asymptotic strategy called the d-function model. This has the advantage that complex cure kinetics can be handled with as much ease as simple kinetics. We present two-dimensional stability results and show that for nth-order kinetics, one-dimensional results will suffice.

3. Most diffusion flames have edges, regions where mixing can occur. Edges are a characteristic of flames held by flame-holders, of fire-spread over solids or liquids, and of turbulent diffusion flames in which holes are generated by high turbulence levels. Flame-holding and turbulent non-premixed combustion is an important issue in turbines, ram/scram engines, and the burning of heterogeneous propellants in rocket engines. We have developed a new one-dimensional model of edge-flames which promises to make clear much of the physics that controls these edges, and we have applied it to a number of situations. [19] is the best representative of this work, and its abstract reads:

Edge-flames arise in non-premixed combustion, and include the familiar triple, or tribrachial flames. They can exist for all Damkohler numbers for which the upper and lower branches of the S-shaped response of the underlying diffusion flame simultaneously exist, and have negative propagation speeds (corresponding to failure waves) when the Damkohler number is close to the quenching value, positive speeds (corresponding to ignition waves) when the Damkohler number is close to the ignition value. A previously described one-dimensional model of edge-flames is here applied to a number of new situations. These include: a description of unbounded edge-flames, for unit Lewis numbers, over the entire range of Damkohler numbers; a description of unbounded edge-flames when one of the Lewis numbers differs from unity, for which it is shown that propagating edge-flames of stationary structure may not exist; and an analysis of an edge-flame near a wall, sans flow between the wall and the flame. In the case of unbounded edge-flames, a simple formula for the edge-speed is derived that may be of value in the computation of turbulent combustion fields in the laminar flamelet regime.

Presentations and service

A joint US/Japan workshop on modeling in combustion, sponsored by NSF and JSPSS, was held in Kauai, Hawaii in July 1994. The co-organizers of this conference were T.Takeno (University of Nagoya) and the principal investigator.

Invited talk at the ESF/FBP workshop 'Free Boundary Problems in Combustion', held in Arcachon, France, March 22-24, 1995. Travel expenses were paid by the workshop organizers.

Seminar at the University of Colorado, Boulder, March, 1995.

Invited talk at the Gordon Research Conference 'Gravitational effects in physicochemical systems', July 9-14, 1995. All expenses were paid by the organizers.

Plenary lecture at the Fall Technical Meeting of the Eastern States Section of the Combustion Institute, October 16-18, 1995.

Talk at the International Conference on the Dynamics of Explosives and Reactive Systems, Boulder, Colorado, July, 1995.

Talk at The American Physical Society Division of Fluid Dynamics annual meeting, November 1995.

The PI was co-chair and co-organizer (with M.Smooke and D.S.Stewart) of the Sixth International Conference on Numerical Combustion, held in New Orleans in March 1996. Care was taken to ensure that the program included elements of particular interest to AFOSR.

Seminar at Yale University, Department of Mechanical Engineering, 1996.

Talk at the 19th International Conference on Theoretical and Applied Mechanics, Kyoto, Japan, 1996.

The PI was appointed to the editorial board of a new combustion journal, to be published by the Institute of Physics (UK), called Combustion Theory and Modelling.

The PI was appointed program chair of the 1999 International Conference on the Dynamics of Explosions and Reactive Systems, to be held in Heidelberg.

The PI was appointed member of the Publication Committee, advisory to the Board of Directors of the Institute for the Dynamics of Explosions and Reactive Systems.

The PI was invited to submit a paper for a special combustion issue of the Journal of Engineering Mathematics, edited by N.Peters. See [19].

The PI received an invitation to present a lecture at a workshop to mark the 70th birthday of John Clarke, to be held at Cambridge University, England, in April 1997. Expenses will be paid by the host.

Honors.

Senior U.S. Scientist Award (Humboldt Prize), 1985, 1986
Buckmaster, J.
Alexander von Humboldt Foundation, Germany

JSPS Fellow, 1986
Buckmaster, J.
Japan Society for the Promotion of Science, Japan

Fellow, American Physical Society, 1986
Buckmaster, J.
American Physical Society, USA

Guggenheim Fellowship, 1990
Buckmaster, J.
Guggenheim Foundation, USA

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